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The Effects of Ski Goggles' Induced Field and Tint on Stability and Balance

By

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Kevin Loopeker is originally from Richmond, British Columbia. Kevin graduated from the University of British Columbia in 1996 with a Bachelor of Science Degree in Honors Physiology. While at UBC, Kevin was a member of the Kappa Sigma Fraternity. Kevin's current optometric interests lie in sports vision and vision therapy, and he is hoping to establish an optometric practice somewhere along the Pacific Coast. Kevin's interests include sailing, hiking, volleyball and soccer. Kevin currently resides in Langley, BC.

Brian Rowley was born in Richfield, Utah. He graduated from Brigham Young University in 1996 with a Bachelor of Science Degree in Family Science. He Married Emily Loretta Nelson in December 1994. He currently is a father of two wonderful boys, Nathan age 5, and Tyler age 2. When not doing optometry, Brian enjoys participating in athletic events, as a participant and a fan, and spending time in the great outdoors hunting and fishing, however his first love is his family. His current optometric interest is to incorporate sports vision in a private practice setting.

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Abstract

Subjects (n=30) were exposed to four goggle-induced visual conditions while attempting to balance on a Lafayette stabilometer. Subject participated in eight, one-minute trials that included two random exposures to each of the four testing conditions: no goggle, clear goggle, tinted goggle and reduced field. Both the duration and frequency of the stabilometer's oscillation between a stable and non-stable position was measured. Only the reduced field goggle condition statistically impaired the subjects' ability to maintain their balance on the stabilometer. Despite randomization and two practice trials before testing, subjects experienced a significant learning effect between their first and second exposure to each testing condition.

Introduction

A large majority of skiers and snowboarders wear goggles. These goggles play an important role in improving visibility by limiting the amount of light to the eye, reducing glare, and acting as a barrier to the wind and cold. Filtering too much or too little light can make it difficult to see the shades and contours of the ski slope, while not protecting the eyes from the wind and cold can blur vision, increase tearing, and decrease the perception of snow contours[1]. Most, if not all, currently available goggles filter out ultraviolet radiation (UVR) (<400 nm)[2] to protect the eyes from sunburn, keratoconjuctivitis, pterygia, pinquecula and cataracts. UVR protection is particularly important during skiing because of the increased risk due to snow reflectivity (clean new snow reflects about 80% of UVR[3]) and higher altitudes (less atmosphere to absorb the UVR). Goggles also protect the eyes from mechanical injuries such as corneal abrasions caused by tree branches, the most common ocular injury in alpine and cross-country skiing[4]. Goggles can also prevent more serious blunt or perforating injuries caused by an errant ski or ski pole tip.

For years, goggle companies have been marketing their products to the recreationalist and elite competitor claiming that their eyewear is superior. Style, comfort, safety, visual clarity and price are all important factors considered when selecting eyewear; however, it is the elusive performance factor that is often the most sought after attribute, particularly for the advanced performer. Can one brand of goggles improve ski performance better than their competitor? Sound reasoning suggests that a lens providing superior clarity, contrast sensitivity and depth perception will permit the wearer to examine the course more critically and find the most efficient and fastest line down the course. Unfortunately, despite what the manufacturers may claim, there is often little more than anecdotal evidence to support their claims.

Yellow or amber tinted lenses have been popular with skiers due to subjective observations that they darken shadows and accentuate the undulations in the snow[5,6]. Recent studies have demonstrated the physical and physiological basis for these subjective observations. Chung and Pease[7] report that pupil diameter is larger with a yellow lens than when viewing a broad-spectrum white field at an equivalent luminance. Kinney et al.[8] compared luminance-matched yellow-tinted and neutral goggles in outdoor snow conditions and found the yellow-tinted lenses provided better depth perception and contrast sensitivity, particularly on overcast days. Kinney et al.[9] also found faster reaction times with yellow goggles than with luminance-matched neutral conditions in frequencies in the middle of the range of human sensitivity, especially the lower contrasts of these frequencies. Yap[10] reports improved monocular contrast sensitivity with the yellow filter under photopic conditions, but not significantly at most spatial frequencies under mesopic conditions.

In recent years, the market has been flooded with lens tints encompassing the entire color spectrum, all claiming to provide superior visibility in all sorts of weather and snow conditions. In one study investigating these claims, Glenn et al.[11] compared the effects of gold, vermilion and gray tinted goggles on vision and skiing performance. They found no significant difference in visual acuity, contrast sensitivity, or Giant Slalom ski time trials, although the expert skiers subjectively preferred vermillion. Polarizing lenses can reduce glare, but may eliminate too much information about the slope face to be beneficial for racers. Polarizing lenses will also transmit an ever-changing amount of light depending on the variable polarizing angle created by the orientation of the sun, snow surface and lens.

To date, much of the goggle research has focussed on improving visibility. As the basis for this project, no research, to our knowledge, has been conducted to examine what effect the goggle has on peripheral vision, stability and balance, and how it may ultimately influence "on-snow" performance.

Most sports require athletes to visually process several events at the same time. Athletes are constantly using their central vision to follow one specific object (e.g. the ball or an opposing play) while simultaneously using their peripheral vision to be aware of what is occurring around them. For example, as Getz[12] explains, a football quarterback with poor peripheral vision will have difficulty finding his open receivers and evading the defensive linebackers coming at him. Without peripheral vision, the quarterback will not know where the line of scrimmage or other boundaries of the field are, nor will he be able to maintain his balance as he scrabbles out of the pocket sidestepping the outstretched arms. Getz believes peripheral vision is so critical to an athlete's success that he suggests that it may be one of the major differences that separate superstars of the National Basketball Association from other NBA players[8]. Sherman[13] stresses the importance of peripheral awareness in sports performance and Paulus et al.[14] stresses the dominant role vision has in maintaining upright posture during demanding balancing tasks such as sports or riding a bike. Peripheral visual awareness and visually-guided balance are felt to be so important in the performance of athletes, that they are routinely tested in standardized optometric assessment of visual performance of athletes[15].

The American Optometric Association Sports Vision Section Guidebook (Volume 5) provides a thorough description of the visual skills important to skiing[16]. In it, Haleo differentiates three separate sub-levels of peripheral vision necessary for skiing: peripheral vision, peripheral awareness and central-peripheral awareness--terms often used synonymously for one another. Peripheral vision is the ability to see objects in the peripheral field of view, such as skiers and other obstacles[19]. Peripheral awareness is the dynamic ability to use peripheral visual stimuli to determine self-direction and spatial localization relative to oneself. It is used to determine where the skier is on the racecourse and how close he/she is to the turn markers. Central-peripheral awareness is the ability to process and integrate peripheral visual information, while maintaining fixation and concentration on a central task. How much each component influences a skier is debatable and the research is scarce or non-existent. Haleo claims peripheral awareness is a very important skill in recreational and high-altitude skiing, but is not as important in Slalom or NASTAR (National Standards Race) racing. Loran and MacEwen[17] report central-peripheral awareness is very important in all types of skiing, particularly for the competitive skier. Rousseau, Amyot, and Labelle[18] also emphasizes the importance of peripheral vision in skiing, particularly as the level of competition and speed increases. Regardless of these subtle distinctions, peripheral visual cues have a very important role in spatial awareness, balance and stability.

The peripheral retina influences balance and stability via the magnocellular pathway's link to the vestibular system. Approximately 20% of the nerve fibers that leave the eye, via the optic nerve, go to balance control centers within the brain. The magnocellular, or "where," pathway receives visual information from cells equally distributed throughout the retina and codes for movement. This is distinctly different from the parvocellular, or "what," pathway that receives most of its visual information from cells densely surrounding the central fovea and codes for fine detail. The organizational and functional differences between the two pathways make the peripheral retina more sensitive to motion than the central retina, at the expense of spatial detail. Ambland et al.[19] concludes that this visual perception of movement is one of the critical factors in equilibrium maintenance.

Dickinson and Leonard[20] demonstrated peripheral vision's role in balance and postural stability when they significantly decreased their subjects' ability to balance when standing, by restricting their subjects' central field of view to approximately 40° using ¾" apertures. They also discovered balance would improve with training that emphasized using peripheral cues. Dickinson and Leonard concluded that "any restriction in peripheral vision and corresponding decrease in information regarding body position is likely to cause an immediate decrease in ability to balance." They believed that peripheral vision provided essential information about body posture that a less finely discriminatory kinesthetic system could not provide.

Alfano and Michel[21] also demonstrated the important role of peripheral vision in integrating visual information with body motion and cognition. Subjects performed various tasks requiring walking, reaching and forming a cognitive room map, while wearing goggles that limit the normal field of view to 9, 14, 22 and 60 degrees. Each restriction of peripheral field of view resulted in some perceptual and performance decrements, with the 9 and 14 degree restrictions producing the most disturbances. Bodily discomfort, dizziness, unsteadiness and disorientation were also reported. According to Pelli[22], a 9-degree visual field should disrupt competent visuomotor and cognitive performance, a 14-degree visual field should yield competent performance, and a 22-degree visual field restriction should yield no measurable performance decrement.

One of the best real-life examples of the importance of peripheral vision in sports comes from the translated copy of *Studies in Physiology of Exercise*, A.N. Krestovnikov (Moscow, USSR, ~1950). In their review of this book, Graybiel, Jokl, and Trapp[23] described how Soviet athletes in many different sports (downhill skiing, javelin, discus, ice skating, 400m track and gymnastics) performed under several visual field restrictions. These conditions included normal unobstructed vision, peripheral vision occlusion, central vision occlusion and binocular occlusion. Peripheral vision was eliminated using goggles from which tubes 18 to 30 cm and 1 to 3 cm in diameter protruded; central vision was eliminated by close-fitting glasses whose centers were covered by paper circles. In all sports, except running, peripheral vision occlusion significantly reduced performance and often degraded performance more than central occlusion.

Although, no one has been able to prove that visual field size is directly related to performance, it has been demonstrated several times that skilled athletes do have larger visual fields than non-athletes [24,25,26,27]. Individuals have different peripheral awareness abilities based upon perceptual and cognitive factors[28,29], including fatigue and anoxia[30]. Also, increased life stress causing peripheral narrowing has even been correlated with increased athletic injury[31]. Knowing that higher-level athletes possess larger visual fields than non-athletes, these higher-level athletes may be more sensitive to restrictions in their field of view than their non-athletic counterpart.

In the Russian skiing tests, expert skiers raced down a 150m slalom course (number of participants, trials, or time standard deviations are not known). The average skiing times were 25.6 sec for full vision, 27.6 sec for central occlusion and 32.1 sec for peripheral occlusion. While central vision exclusion produced only minor motor control difficulties, peripheral occlusion made it exceedingly difficult to follow the course. Ski tracks were uneven and judgement of distances was almost impossible. The researchers concluded elimination of peripheral vision caused much more marked deterioration than central occlusion.

Several studies have been conducted to assess whether sport protective eyewear decreases peripheral vision, with the intent of linking a reduced field of view with a reduction in performance. Several studies have tested hockey face shields[32,33] and racquetball eyewear[34,35], but to our knowledge,none have been performed with ski or snowboard goggles. All of these studies used clinical perimetry to evaluate the degree of field loss, and all, except for Arbet et al.'s goalie mask study, claim that peripheral vision was not significantly reduced. Few of these studies justified the field loss they considered to be insignificant, especially since none of them had a performance test to support their conclusions. Gallaway et al.[36] was one of the exceptions; however, they were testing central-peripheral awareness rather than stability and balance. Although they found sport glasses did restrict visual field, they concluded that these restrictions did not translate into significant decreases in performance of task.

Based on the current research presented above, goggle design has the potential to significantly reduce the wearer's peripheral field of view. Such limitations may have a detrimental effect on balance and postural stability. The skier, as Getz[37] suggests, may have to be more actively engaged in acquiring information to maintain balance, and therefore cannot concentrate as efficiently as possible to the actual run. As Coffey and Reichow point out[38], this momentary attention shift may translate into a loss of momentum and a less than optimal timing of turns through gates and over irregular terrain. In a sport where racers are separated by one hundredths of a second, competitors can not afford to compromise any vision spatial information. The goal of this project was to determine whether goggles restrict peripheral field of view to a level that could interfere with the subjects' sense of balance and stability.

Methods

Thirty adults ranging from 21 to 35 years of age participated in this study (22 males and 8 females). All subjects were required to have habitual binocular visual acuity of 20/30 or better at six meters. Subjects were not allowed to wear spectacle lenses so this had to be achieved with or without contact lens correction. Subjects were required to have no history of vestibular or balance disorders, and no motility limitations. Subjects were required to possess stereo-acuity of at least 120 arc seconds measured by Random Dot stereogram at 40 cm. Subjects were also not allowed to have any prior experience balancing on the Lafayette Stabilometer. All subjects wore running shoes and loose fitting clothing. Subjects were compensated with a free Pass to Nike Employee Store, where subjects had access to discount Nike merchandise.

The balance and stability of each subject was measured using a Lafayette Instrument Co[1]. Stabilometer (Model #16020), a standard clinical instrument used in sports and performance vision testing[39]. The Stabilometer consists of a 104 cm X 64 cm platform suspended 19 cm above the floor by a central fulcrum mechanism that allows the platform to freely tilt laterally to the left and right beyond the horizontal plane. The subjects' goal was to stand on the stability platform and keep it as level as possible while being exposed to the four different testing conditions. In this study, anywhere within 15 degrees of horizontal was considered stable while anything greater than that was considered unstable. During one minute testing trials, three Lafayette Stop Clocks (Model #58007) measured the duration of time the platform was in a stable position (i.e. +/- 15 degree of horizontal) and the Lafayette Data Recorder (Model #58004) counted the frequency the platform toggled beyond the permitted 15 degrees. This instrumentation was connected to a Lafayette Repeat Cycle Timer (Model #51012) and a Lafayette Light Response Control (Model #58036). A metronome (Nikko Seiki Co. LTD) beating at 100 beats per minute was used during all trials to mask the clicking sound the stabilometer. This was done in an attempt to remove any audible feedback of the stability platform's position.

Subjects were required to balance on the for two practice trials without goggles, and then eight test trials, for a total of ten one minute trials. All trials were separated by a one to two minute rest break off the platform to facilitate goggle changing and prevent fatigue. During testing, subjects were instructed to stand on the center of the stabilometer with their feet comfortably placed shoulder's width apart and their knees slightly bent. Projected onto an 8' x 8' projector screen twenty feet in front of the subjects was a static downhill image of a ski slope. In the center of this ski slope was a black 2.5 cm x 2.5 cm "plus sign" that the subjects were asked to fixate during all trials. This fixation target was placed at approximately head height 170 cm above the floor. All testing was done indoors and the stabilometer was placed upon a level floor.

During testing, subjects alternately wore three different pairs of commercially available *Bolle Xeno* ski/snowboard goggles. These goggles contained a double pane polycarbonate lens held within a black opaque plastic frame. Two pairs of *Bolle Xeno Night Ski Clear Black* (Model # 500120010) held a clear transparent lens, while the third pair, a *Bolle Xeno Graphite Citrus* (Model # 5695018601), held a transparent lens that was citrus orange in color (a.k.a. "tinted lens"). One of the clear lenses was used unmodified (a.k.a. "clear lens"), while the other clear lens (a.k.a. "reduced field" lens) was covered with opaque black tape except for two 24 mm circles (the size of a quarter) for the subjects to look through. Together with a control condition of no goggles (a.k.a. "no goggles"), subjects were tested twice in each of these four testing conditions. The sequence of these eight trials (four conditions repeated twice) was randomly determined and did not have both trials coupled together. According to the manufacturer, all goggles had a P-80 Anti-fog coating and were 100% UV protected.

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[1] Lafayette Instrument Co. PO Box 5729, Sigamore Parkway, Lafayette, IN 47903 (800)428-7545

In the reduced field lens, the centers of the two 24-mm transparent circles were 64 mm apart, which corresponds to the mean adult interpupillary distance (IPD) as reported by Pensyl and Benjamin[40]. The vertex distance (VD) from the front goggle pane (where the black tape was placed) to the entrance pupil of the eye on the Canadian Standard Adult Fifty Percentile Male Head was measured to be 30 mm. Using these two measurements, the "average" horizontal monocular field of view of the reduced field lens was 43.6 degrees, while the horizontal binocular field overlap was 21.8 degrees. Although the IPD and effective VD were not measured on every subject, variations in facial characteristics can be estimated. Assuming a constant VD of 30 mm, a 60-mm IPD will reduce the binocular field overlap to 18.4 degrees, whereas a 68mm IPD will increase the binocular field overlap to 25.0 degrees. Note that the monocular field size remains constant and only shifts direction when the IPD changes. Similarly, assuming a constant IPD of 64 mm, a 26 mm effective VD will increase the monocular field to 49.6 degrees and the binocular field to 24.8 degrees, whereas a 34 mm effective VD will decrease the monocular field to 38.9 degrees and the binocular field to 19.5 degrees.

Results:

The data from this study reveal two significant results. Most importantly, it shows that the reduced field goggle was the only condition to significantly impair the subjects' ability to balance on the Lafayette stabilometer. Second, subjects performed better on Trial 2 than on Trial 1. Both of these results are illustrated on Figure 1 and Figure 2. Figure 1 displays the average length of time the subjects maintained their balance within 15° of horizontal under the conditions of no goggle, clear lens, tinted lens and reduced field goggles. Figure 2 displays the average frequency the subjects oscillated between +/- 15° of horizontal and greater than 15° of horizontal for all four conditions. The data for both of these charts are displayed in Table 1 and Table 2, respectively. Note that a longer duration value and lower frequency value indicate superior balancing ability, whereas a shorter duration value and a higher frequency value indicate poorer performance.

Both Figure 1 and Figure 2 illustrate the subjects' reduced ability to maintain the stabilometer horizontal while wearing the reduced field goggles. Figure 1 shows both reduced field trials having significantly shorter duration values compared to any of the other condition trials. Repeated-measure ANOVA of all of the duration data indicates that this is a statistically significant difference ($F(3,87)=46.75$, $p=0$). From visual inspection of Figure 1 and Table 3, it is obvious that this difference is due to a decrease in performance of the reduced field goggle. Similarly, Figure 2 shows both reduced field trials having higher frequency values than any other testing condition. Repeated-measure ANOVA of all of the subjects' frequency data indicates that this is also a statistically significant difference ($F(3,87)=35.11$, $p=0$). Once again, visual inspection of Figure 2 and Table 4 display the obvious difference among the reduced field and the other three testing conditions.

Figure 1 illustrates that the subjects performed better on their second attempt of each testing condition. Note how all of the Trial 2 mean duration values are significantly larger than all of the Trial 1 mean duration values. This indicates an improved ability to balance during the second trial. Table 1 displays the 30 subjects' mean duration value balancing in the stable position for each of the four testing conditions (+/- s.d.). For the condition of no goggle, clear lens, tinted lens and reduced field goggles, the Trial 1 values are 44.27, 43.79, 43.06, and 38.09 seconds, respectively, whereas the Trial 2 values are 47.93, 46.11, 47.00, and 40.49 seconds, respectively (Table 1). The mean average of Trial 1 means is 42.30 seconds and the mean average of these Trial 2 is 45.38 seconds (Table 5). Repeated-measure ANOVA performed on the duration length of the eight trials (four conditions, repeated twice) of all 30 subjects reveal a statistically significant difference between these Trial 1 and Trial 2 duration values ($F(1,29)=45.68$, $p=0$).

Figure 2 also indicates that the subjects performed better on their second attempt of each testing condition. Note the mean frequency values for all four conditions of Trial 1 are larger than the mean frequency values for all four conditions of Trial 2. This oscillation frequency difference indicates that the "average" subject possessed greater stability during the second attempt of every testing condition. Table 2 displays the 30 subjects' mean frequency value oscillating between a horizontal ($<15^{o}$) and non-horizontal ($>15^{o}$) position (+/- s.d.) for each of the four testing conditions. For the condition of no goggle, clear lens, tinted lens and reduced field goggles, the Trial 1 values are 27.87, 29.27, 29.43 and 36.93 cycles per minute (cpm), respectively; whereas the Trial 2 values are 22.30, 25.23, 22.93 and 31.97 cpm, respectively (Table 2). The mean average of these Trial 1 means is 30.88 cpm and the mean average of these Trial 2 means is 25.61 cpm (Table 6). Repeated-measure ANOVA performed on the frequency rate of these eight trials (four conditions, repeated twice) of all 30 subjects also revealed a statistically significant difference between these Trial 1 and Trial 2 duration values ($F(1,29)=78.13$, $p=0$).

ANOVA revealed that there was no significant interaction effect between the goggle conditions and the two trials. This holds true for both the frequency and duration data. ANOVA of the frequency data's interaction effect is $F(3,87)=0.71$, $p=0.548$; whereas, ANOVA of the duration data's interaction effect is $F(3,87)=1.27$, $p=0.290$.

In summary, under these testing conditions, the reduced field goggle was the only testing condition to significantly impair balance and stability on the stabilometer as indicated by the shorter duration values and higher frequency values. Subjects also significantly performed better during on their second attempt trial for each testing condition. There was no significant interaction effect between conditions and trials for both the duration and frequency data.

Discussion:

The purpose of this study was to look at the effects of how four different goggle conditions affected a person's ability to maintain their balance on a stabilometer. The clear lens and the reduced field goggle conditions examined if mild and marked reduction in peripheral vision degraded skier's ability to balance, while the "no goggle" condition acted as the control. The tinted lens condition examined if a colored lens degraded skier's ability to balance, and the clear lens goggle acted as the control condition in this case. The results of this study indicate that the only condition to significantly decrease the subject's ability to balance on the stabilometer was the severely restricted field goggle.

The results indicate that a significant obstruction to the peripheral vision reduces balancing ability. This is not a new discovery and is consistent with the current literature. This effect can easily be demonstrated by comparing how much better a person can balance on one leg with both eyes open compared to their balance when their vision is restricted to looking through two tubes 30 cm long and 3 cm in diameter. This illustration once again demonstrates how important our visual system, particularly our peripheral vision, is to our sense of balance. Visual, vestibular and proprioreceptive systems all provide useful sensory information which our brains integrate together to provide a fully functional balancing system. Missing or conflicting components of this triad can disrupt stability equilibrium, make people feel sick or uneasy (e.g. motion sickness), and interfere with their physical performance. In this study, peripheral vision was the only variable that was altered; however, it is expected that interference with the vestibular and/or proprioreceptive systems would have also negatively impacted stabilometer performance.

The results from this study suggest that peripheral vision has to be significantly reduced before balance is interrupted. This is demonstrated by the substantial decrease in performance with only the reduced-field goggle and by the insignificant difference between the clear goggle and no goggle conditions. Salazar-Sunga, Ichishita and Ly[41] support the fact that the clear goggles actually do restrict some peripheral vision in a companion thesis. It is unclear to what exact extend peripheral vision has to be restricted before balance is significantly affected. In this study, monocular central vision was restricted to approximately 44 degrees before a significant decrease in performance was noted. Perhaps it takes a large restriction in peripheral vision such as this, before balance is adversely affected, or perhaps the stabilometer is not a sensitive enough instrument to assess these small changes in balance and stability. A larger sample size and more sensitive testing instrumentation would offer valuable insight into this question.

This study investigated the effects of decreasing the peripheral field of view and not the effects of reducing the field of binocular overlap. This later characteristic would be particularly useful in design of the nosepiece area. Simple geometry suggests the more the nose-pad area is obstructing the nasal field of view, the less binocular overlap there would be. To what extent this has on skiing performance is unknown; however, it is anticipated that the larger the binocular overlap area, the better the performance. A similar experiment could be designed to test this hypothesis by measuring the effects varying amounts of binasal occlusion.

Whether or not currently marketed goggles reduce peripheral vision enough to significantly impact balance and stability, and by extension, skiing performance, has not been determined in this study (see Salazar-Sunga, Ichishita, Ly); however, our results do suggest that the less the goggle restricts peripheral vision, the better it should perform. This can be accomplished by designing the lens and frame as large as possible to push the opaque frame as far out into the periphery as possible. Making the frame thinner and more transparent may also help. Reducing the vertex distance, the distance between the lens and eyes, is another very effective means of minimizing the frame's interference of peripheral vision.

Most individuals performed better on their second trial in each of the four testing conditions as compared to their first trial. This suggests the exposure the subjects experienced during their first trial for each new "goggle" condition proved to be beneficial to their performance for their second trial. A learning curve, thus, seems to have existed. Despite its existence, it had a negligible effect on the overall outcome because the randomization of the conditions. For example, even subjects who performed the reduced field condition last and had the most experience balancing on the platform, performed better on their second trial than their first trial.

The researchers anticipated this learning period and attempted to eliminate it by including the two-one minute practice trials before actual data collecting began. This number was determined by testing three participants in eight consecutive one-minute trials. They wore no goggles and had a one-minute rest between trials to simulate actual testing design. These test subjects met the eligibility criteria, were randomly selected from the same demographic group as the rest of the participants, and did not participate in the rest of the study. Gross examination of this pre-test trial indicated that these three subjects demonstrated a relatively stable performance plateau after two practice trials; furthermore, the data did not seem to indicate any excessive fatigued after the eight consecutive trials, although, they did indicate they were beginning to get tired near the end. In designing the testing protocol, a balance was sought between the amount of practice required to achieve a stable performance and the added fatigue induced by including too many practice trials before actual testing. This was why only two practice trials were chosen. Unfortunately, the two practice trials do not appear to be sufficient enough to eliminate the "learning effect" experienced by the 30 subjects actually tested. The researchers also did not have the luxury to train the subjects how to balance on the platform days in advance of testing.

In hindsight, there are three ways we could have attempted to reduce this "learning curve" effect to the point of limiting the differences of Trials 1 and 2 to only random errors. The first method would be to increase the number of practice trials immediately before testing. This number would be determined by testing more participants in the pre-study trial to produce a more accurate account of the number of practice trials required to achieve a stable performance on the stability platform. Increasing the number of practice trials immediately prior to testing unfortunately may just replace the practice effect with the fatigue effect.

The second method would be to allow the subjects to practice on the stability platform days in advance of actual testing without any goggles. Although, this second method would potentially reduce fatigue during testing better than the first method, it is hypothesize that substantial practice on the stabilometer may strengthen the subjects' proprioreceptive and vestibular ability so that they may become less reliant upon visual input. Thus, the subjects may become less sensitive to reductions in their peripheral fields if they learn how to use their other sensory systems (e.g. proprioreceptive and vestibular) more effectively. Investigations into vision's role in the maintenance of dynamic balance support this theory by discovering that expert gymnists are much more capable of walking across a balance beam with their vision completely eliminated than their novice counterparts[42,43].

The third method would be to have the subjects do ten trials and then only statistically analyze the best three or four results. The disadvantage of this method is that the results can be unfairly skewed if a subject performs uncharacteristically well in one or two trials. This method has the potential to artificially polarize the statistical significance of the results.

In actuality, the learning curve probably can not be completely eliminated. Different people learn at different rates and some have naturally better adapting and balancing abilities. In our subject pool, some subjects adapted very quickly, whereas other did not appear to achieve a stable performance level even after eight trials. If the learning curve was eliminated completely, perhaps other variables, as suggested above, would be introduced that would alter the results that were found. This would need to be explored in future investigations. Regardless of the effect of the learning curve, randomization obviates the argument that these effects are all due to learned effect.

The results from this study indicate that restricted illumination created by a tinted filter does not significantly affect the subject's ability to balance on the stabilometer. This is shown by the equal performance of the clear and tinted lens goggles. If a fifth goggle condition consisting of a reduced field tinted goggle was performed, we would not expect a worse performance than the clear reduced field lens alone. In this study, we did not quantify the difference in the amount of illumination between these two conditions, nor did we quantify the specific wavelengths transmitted; however, by definition, the tinted lens transmits only a portion of the light transmitted through the clear lens due to its ability to selectively filter a specific portion of the visible spectrum. Although only one tinted lens was tested, our data suggests that colored filters do not significantly influence the wearers any more than a clear lens does, unless perhaps illumination is reduced to such a level that overall vision is restricted. This of course, does not address any of the other benefits colored lenses, such as visual clarity or comfort, that some colored lenses are reported to possess. The results from this study indicate that restricted illumination created by a tinted filter does not significantly affect the subject's ability to balance on the stabilometer. This is shown by the equal performance of the clear and tinted lens goggles. If a fifth goggle condition consisting of a reduced field tinted goggle was performed, we would not expect a worse performance than the clear reduced field lens alone. In this study, we did not quantify the difference in the amount of illumination between these two conditions, nor did we quantify the specific wavelengths transmitted; however, by definition, the tinted lens transmits only a portion of the light transmitted through the clear lens due to its ability to selectively filter a specific portion of the visible spectrum. Although only one tinted lens was tested, our data

suggests that colored filters do not significantly influence the wearers any more than a clear lens does, unless perhaps illumination is reduced to such a level that overall vision is restricted. This of course, does not address any of the other benefits colored lenses, such as visual clarity or comfort, that some colored lenses are reported to possess. Given two goggles with identical tints, this study suggests choosing the one with the largest field of view.

In this study, subjects were not exposed to the high velocities and demanding environment conditions encountered by skiers. Since it is obvious that the conditions under which the testing was conducted did not simulate actual skiing conditions, the question regarding the transferability of the results from the indoor laboratory to the actual ski slope can be raised. The two biggest differences that we feel to be important between our testing conditions and those experienced while skiing is the type of illumination and skill correlation between skiing and the stabilometer.

Skiers and snowboarders experience a wide variability of natural lighting conditions even within a single race. Sun position, snow, clouds, shadows, fog, snow reflectivity, and glare are factors that can instantaneously change the amount and type of sunlight that skiers experience. Sunlight possesses a different wavelength profile than fluorescent lighting; however, the variability of lighting conditions that skiers experience is so variable that it is impossible to simulate all of them indoors. The real benefit of the indoor illumination is its consistent nature, something that is virtually impossible to control if the testing was conducted outdoors on a real ski slope. Besides, the authors could not find any evidence in the literature suggesting that sporting performance differences exist under natural and artificial lighting, except possibly for color discrimination[44].

It is quite evident that balancing on the stabilometer does not replicate the actions involved in skiing. Whereas skiing involves balance maintenance while moving through all three dimensions, the stabilometer requires only lateral balance across the sagittal plane. Subjects also maintained a horizontal anterior-posterior orientation unlike the customary downhill sloping orientation experienced in skiing. Subjects were told they could adopt a skiing-like posture if they wanted as long as they were consistent throughout testing; however, the vast majority of subjects chose to stand upright with their knees slightly bent and arms extended. All subjects wore running shoes and therefore probably experienced different proprioreceptive stimuli than if they had worn skiing or snowboarding equipment. Despite all of these physical differences between actual skiing and using the stabilometer, it is felt that all of the conclusions this study can be fundamentally transferred to the ski slope.

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Tables:

Table 1: Mean duration subjects (n=30) were able to maintain their balance within the +/-15 degree horizontal stability zone for the four testing conditions of one minute duration

		Duration (s)		
Condition	Trial	mean	s.d.	SEM
No goggle	1	44.27	5.5	1
	2	47.93	5.98	1.09
Clear lens	1	43.79	6.68	1.22
	2	46.11	5.33	0.97
Tinted lens	1	43.06	5.83	1.06
	2	47	6.53	1.19
Reduced field	1	38.09	5.23	0.96
	2	40.49	5.38	0.98

Table 2: Mean frequency subjects (n=30) oscillated outside the permitted +/-15 degree horizontal stability zone of the four testing conditions of one minute duration

		Frequency (cpm)		
Condition	Trial	mean	s.d.	SEM
No goggle	1	27.87	9.89	1.8
	2	22.3	10.26	1.87
Clear lens	1	29.27	12.55	2.29
	2	25.23	10.71	1.96
Tinted lens	1	29.43	9.83	1.8
	2	22.93	10.17	1.86
Reduced field	1	36.93	11.19	2.24
	2	31.97	10.22	1.87

Table 3: Mean duration (combining Trials 1 & 2) subjects (n=30) were able to maintain their balance within the +/-15 degree horizontal stability zone for the four testing conditions of one minute duration

	Duration (s)	
Condition	mean	s.d.
No Goggle	46.10	2.59
Clear Lens	44.95	1.64
Tinted Lens	45.03	0.49
Reduced Field	39.29	1.70

Table 4: Mean frequency (combining Trials 1 & 2) subjects (n=30) oscillated outside the permitted +/-15 degree horizontal stability zone of the four testing conditions of one minute duration

	Frequency (cpm)	
Condition	mean	s.d.
No Goggle	25.09	3.94
Clear Lens	27.25	2.86
Tinted Lens	26.18	4.60
Reduced Field	34.45	3.51

Table 5: Mean duration (combining all four testing conditions) subjects (n=30) were able to maintain their balance within the +/- 15 degree horizontal stability zone for Trials 1 and 2

	Duration (s)	
Trial	mean	s.d.
Trial 1	42.30	2.85
Trial 2	45.38	3.35

Table 6: Mean frequency (combining all four testing conditions) subjects (n=30) oscillated outside the permitted +/- 15 degree horizontal stability zone for Trials 1 and 2

	Frequency (cpm)	
Trial	mean	s.d.
Trial 1	30.88	4.10
Trial 2	25.61	4.42

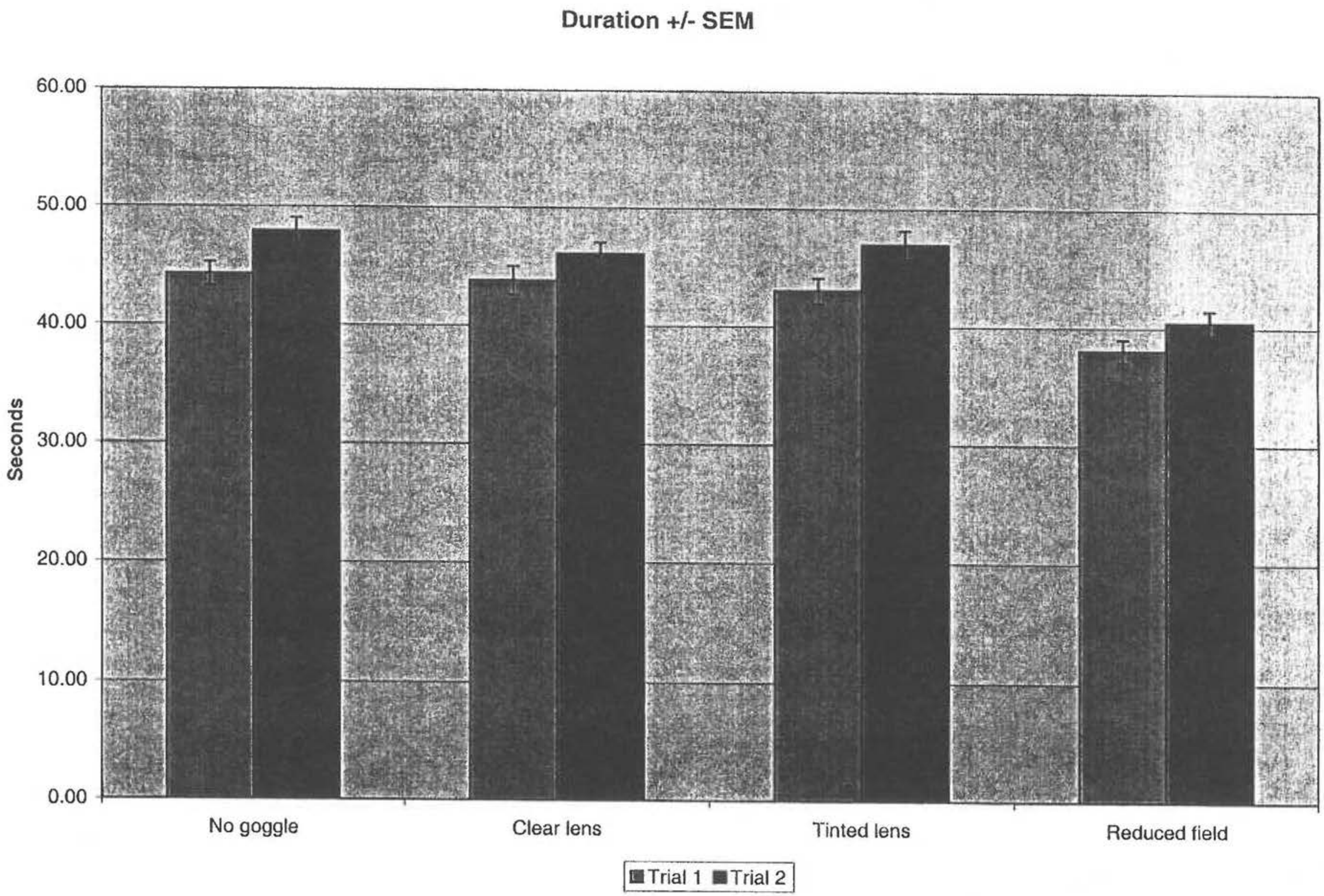
Duration +/- SEM
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Seconds
No goggle
Clear lens
Tinted lens
Reduced field
Trial 1
Trial 2

Figure 1

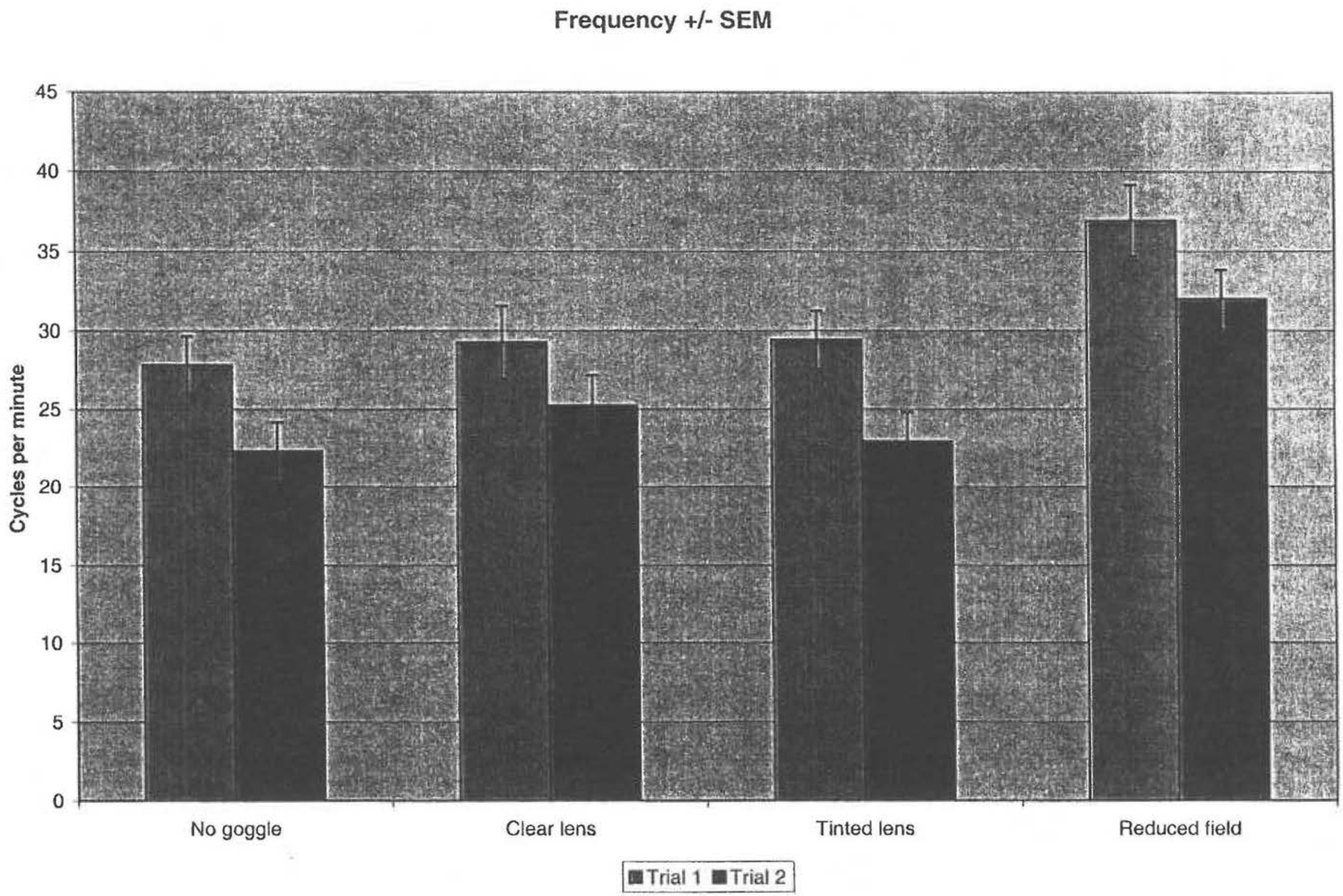
Frequency +/- SEM
Cycles per minute
45
40
35
30
25
20
15
10
5
0
No goggle
Clear lens
Tinted lens
Reduced field
Trial 1
Trial 2

Figure 2

Appendix: Raw Ski Goggle Data

Values are given as "centered" times only. Time in seconds and frequency (freq) in cycles per minute.

Subject	No Goggle				Clear Lens				Tinted Lens				Reduced Field			
	Trial 1		Trial 2		Trial 1		Trial 2		Trial 1		Trial 2		Trial 1		Trial 2	
ID No	Time	Freq	Time	Freq	Time	Freq	Time	Freq	Time	Freq	Time	Freq	Time	Freq	Time	Freq
1	45.6	15	57.5	4	52.6	10	51.6	7	45.1	15	55.6	4	36.6	19	40	18
2	42.5	25	39.7	26	32.5	30	46.7	17	34.8	35	47	16	36.9	28	41.1	23
3	54.7	11	55.3	12	49	17	55.6	12	47.5	21	53.5	16	41.5	31	43.6	29
4	47.81	28	49.2	27	39.1	44	44.9	36	43.1	36	49.6	27	37.1	45	35.3	49
5	47.5	25	56.1	7	53.1	15	55.2	12	51.1	19	54.6	14	51	17	51.4	18
6	46.1	21	45.1	19	42.9	42	46.5	22	43.5	32	45.8	24	35.3	37	36.3	33
7	43.7	33	43.3	32	38.5	41	39	37	40.3	40	38.8	40	35.5	47	33.6	47
8	39	30	44.3	25	43	33	42.3	31	37.8	33	39.2	35	32.6	45	36	41
9	52.6	15	52.4	14	52.2	16	46.1	24	50.2	14	53.9	10	48.2	20	48	19
10	43.6	16	50.1	10	49.9	13	45.5	13	47.3	14	50.6	9	37.2	25	43.6	19
11	44.9	29	47.4	20	48.6	21	45.1	22	43.7	33	50.2	15	40.8	32	43.5	23
13	42.2	48	46.7	36	45.7	37	44.5	44	40.4	48	45.2	36	37.4	53	40.7	43
14	41.2	23	52	14	37.6	29	46.8	19	42.7	20	50.8	12	41.1	24	38.6	22
15	47	31	49	28	46.7	30	51.9	19	41.1	40	49	28	31.2	53	46.4	34
16	43.2	42	41.9	40	37.7	53	41	38	44.1	38	40.2	36	33.4	57	35.1	46
18	38	30	49.5	20	43.5	23	46	26	42.6	25	50.9	19	43.1	25	45.1	22
19	42.1	27	40.4	33	44.1	25	44	17	38.5	27	43.5	27	34.9	31	35.7	28
20	45.2	47	49	36	42	46	44.5	50	39.8	48	47.8	30	33.2	51	38.6	53
21	49.3	30	54.7	17	50.7	26	51.7	24	54.5	19	54	19	46.6	38	47.3	38
22	30.3	30	35.9	26	32.5	28	36.8	28	29.2	28	30.6	26	30	27	34.7	26
23	50.4	21	54.6	13	53.2	13	51.6	20	40.2	36	52.4	16	37.4	48	49.3	24
24	38.2	29	42.9	24	36.6	29	38.4	29	31.8	38	33.5	27	33.2	39	38.9	36
25	41.3	47	44.9	36	42.9	46	43.9	37	44.7	41	43.3	41	44.9	49	41.4	35
26	41.3	33	50.4	21	37.4	46	41.6	34	46.4	30	42.8	32	39.5	37	38.2	39
27	52.3	12	58.1	4	52.8	12	56.1	9	44.8	25	57	6	36.3	36	44.9	24
28	34.4	31	37.9	32	31.8	36	34.8	37	35.3	28	40.2	30	30.3	51	27.2	37
29	38.4	38	41.4	36	36.8	44	46.5	24	41.4	37	41.6	29	38.5	40	34.8	42
30	48.3	24	52.8	16	46.4	22	48.5	20	50.2	19	50.6	17	40.5	31	43.1	24
31	50.6	16	51.3	13	51.7	12	50.1	16	50.6	16	50.1	16	35.1	32	39.5	27
32	46.5	29	44.2	28	42.1	39	46	33	49	28	47.6	31	43.4	40	42.9	40
n	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
mean	44.27	27.87	47.93	22.30	43.79	29.27	46.11	25.23	43.06	29.43	47.00	22.93	38.09	36.93	40.49	31.97
s.d.	5.50	9.88	5.98	10.26	6.68	12.55	5.33	10.71	5.83	9.83	6.53	10.17	5.23	11.19	5.38	10.22
SEM	1.00	1.80	1.09	1.87	1.22	2.29	0.97	1.96	1.06	1.80	1.19	1.86	0.96	2.04	0.98	1.87